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H04L 25/02

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H4P PRE

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DE 019810285 A1
WO 1998/037671 A1
US 5887027 A

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INT CL^7 **H04L** 25/02 25/03
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(54) Abstract Title

Method for setting up a precoder in a subscriber unit of a wireless transmission system

(57) A method of setting the characteristics of a precoder in a Mobile/Subscriber Unit (SU) in a point to multi-point wireless transmission system comprising a Base station/Access Point (AP) and a plurality of SUs, the method comprising the steps of:

a) the AP transmitting downstream data frames, containing a training identifier field, containing a unique identifier and defining a time at which an associated upstream training test field occurs;

b) the SU, storing the unique identifier and generating and transmitting an upstream test sequence in the training test field;

c) the AP storing samples of the received training test sequence;

d) the AP transmitting a training response field, the training response field containing the unique identifier and data representing the impulse response of the upstream channel; and

e) the SU adjusting its precoder characteristics in accordance with the upstream channel impulse response data.

The precoder is intended to pre-equalise/pre-distort the signal to compensate for the effects of the channel.

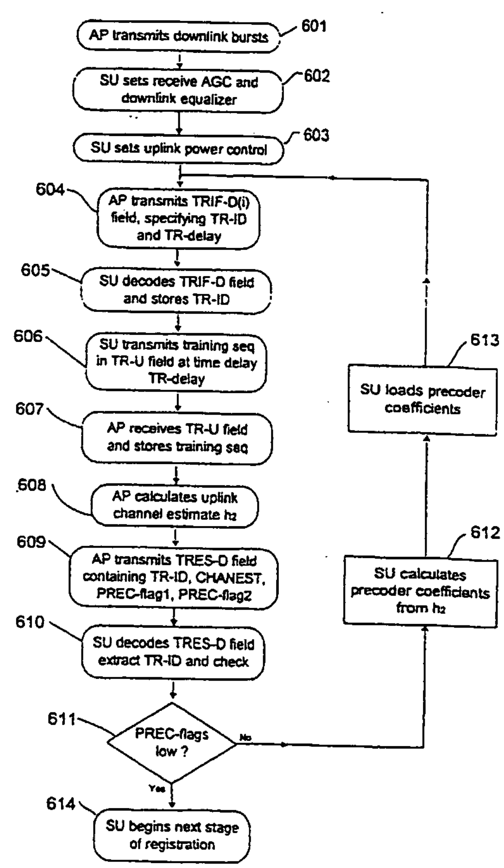


Figure 6

GB 2 376 391 A

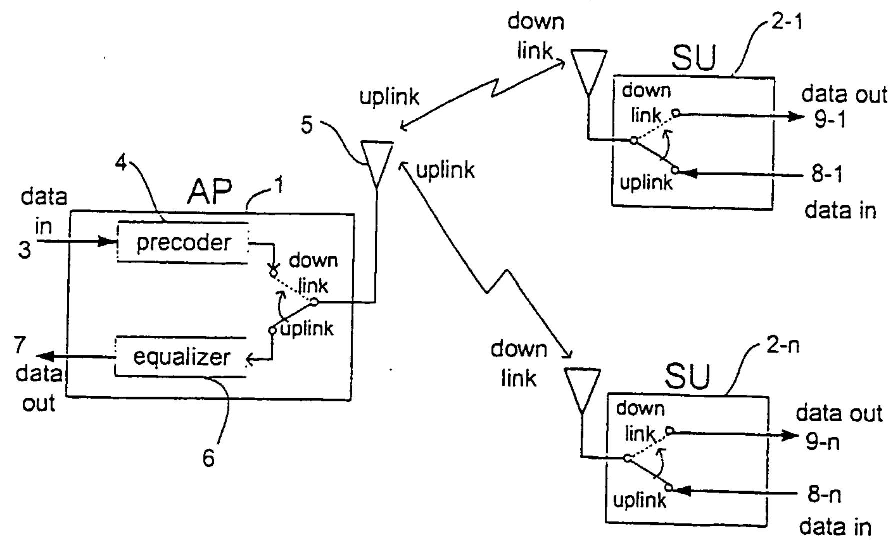


Figure 1 (PRIOR ART)

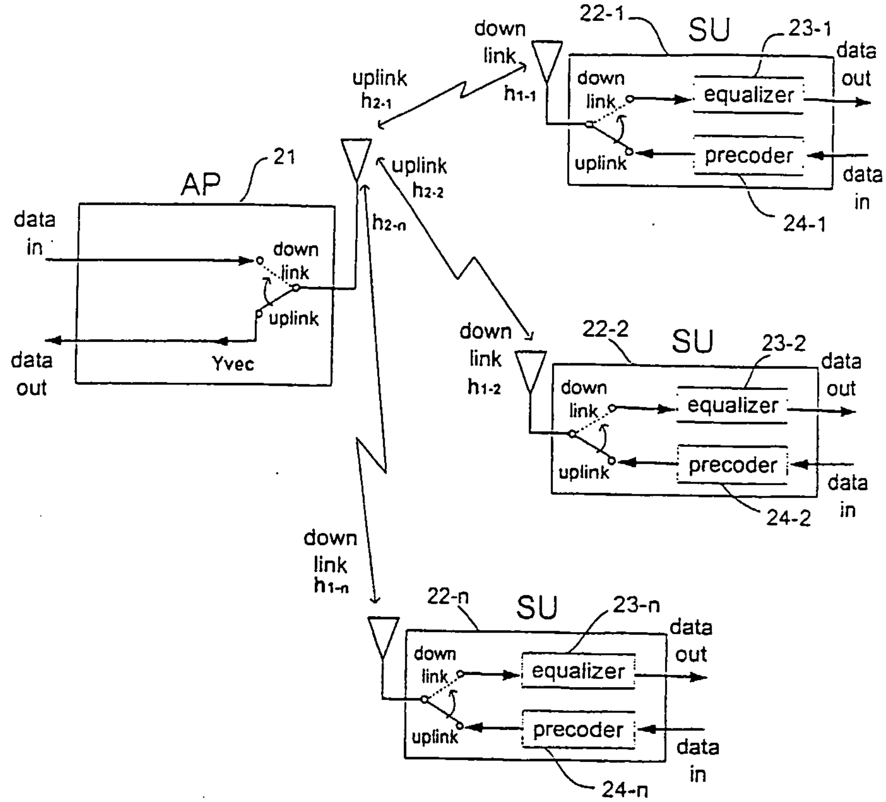
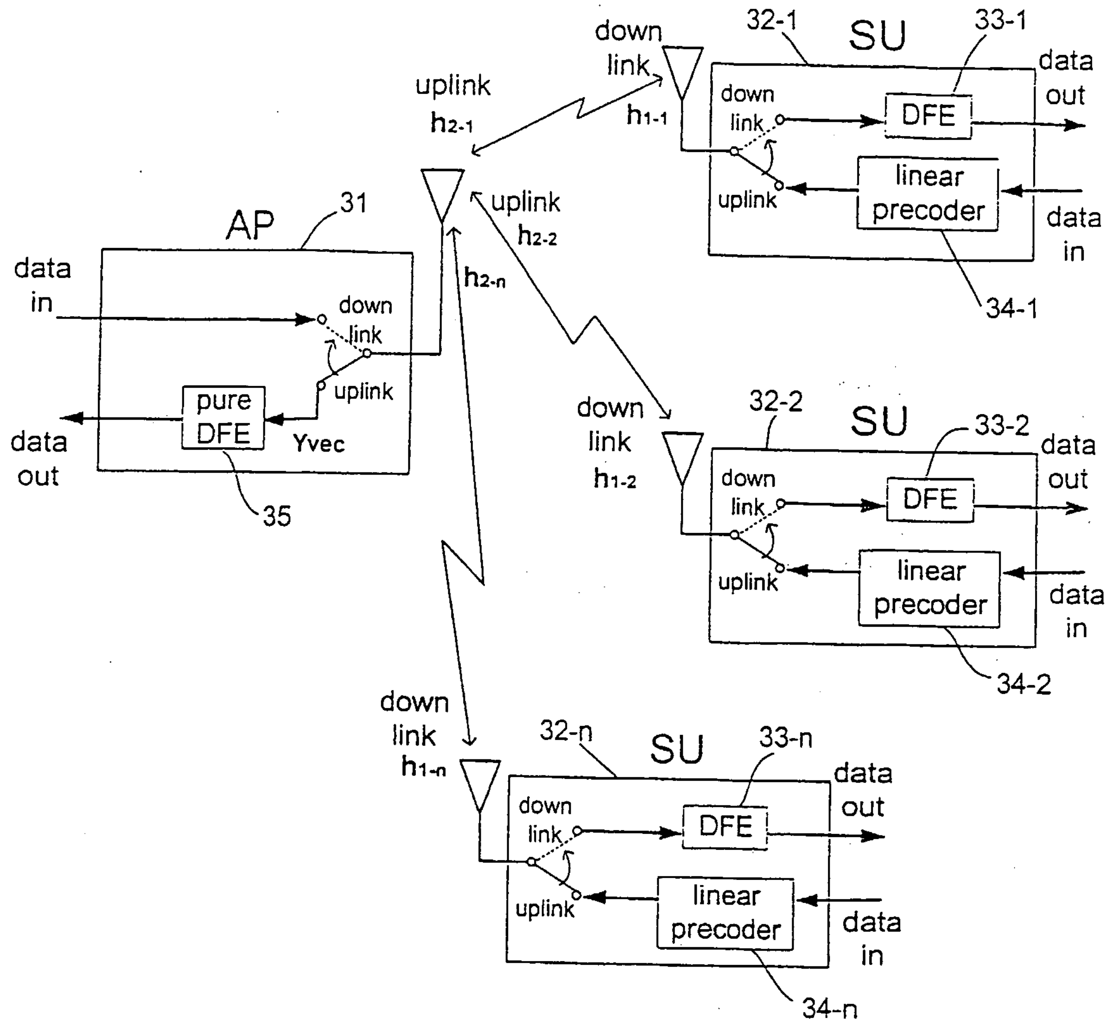

AP
21
data in
down link
uplink
data out
Yvec
uplink h2-1
uplink h2-2
h2-n
down link h1-1
22-1
SU
23-1
down link
equalizer
data out
uplink
precoder
data in
24-1
down link h1-2
22-2
SU
23-2
down link
equalizer
data out
uplink
precoder
data in
24-2
down link h1-n
22-n
SU
23-n
down link
equalizer
data out
uplink
precoder
data in
24-n

Figure 2



AP
31
data in
down link
uplink
pure DFE
Yvec
data out
35
uplink h2-1
uplink h2-2
h2-n
down link h1-1
SU
32-1
33-1
down link
DFE
data out
uplink
linear precoder
data in
34-1
down link h1-2
SU
32-2
33-2
down link
DFE
data out
uplink
linear precoder
data in
34-2
down link h1-n
SU
32-n
33-n
down link
DFE
data out
uplink
linear precoder
data in
34-n

Figure 3

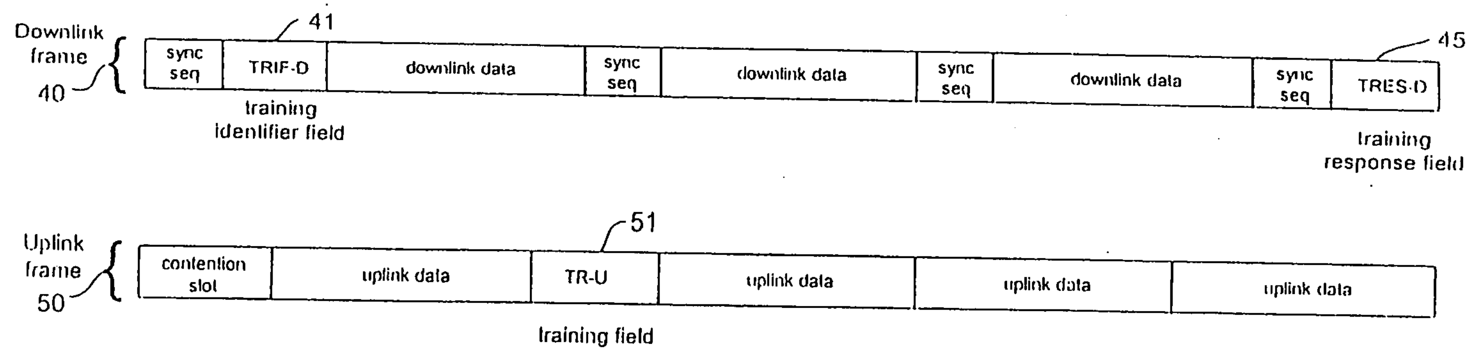


Figure 4

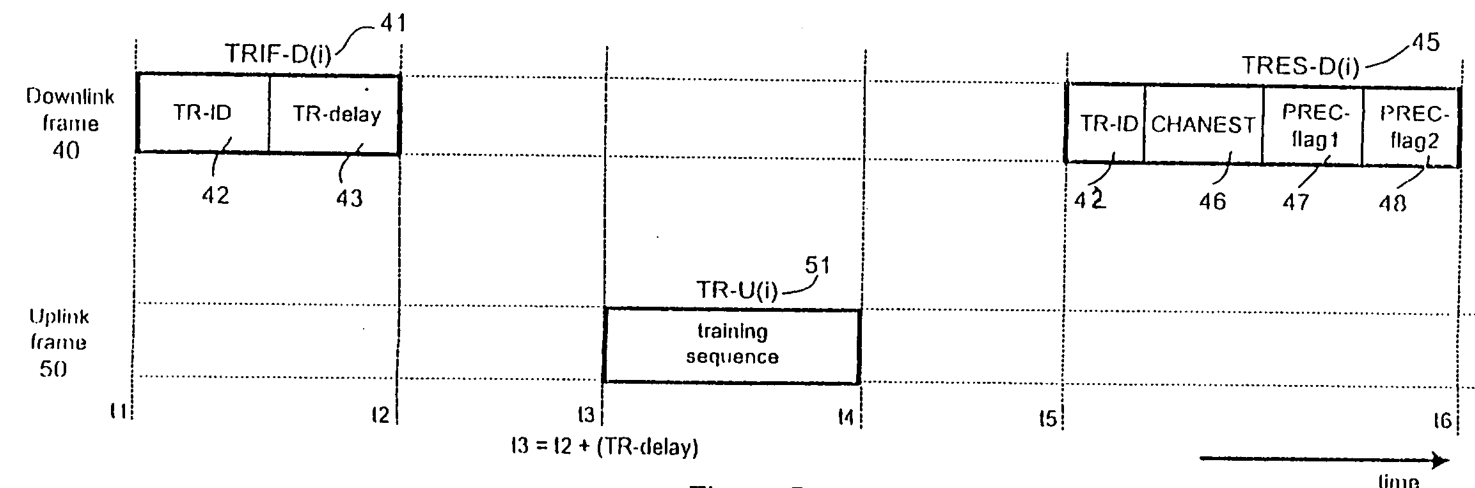


Figure 5

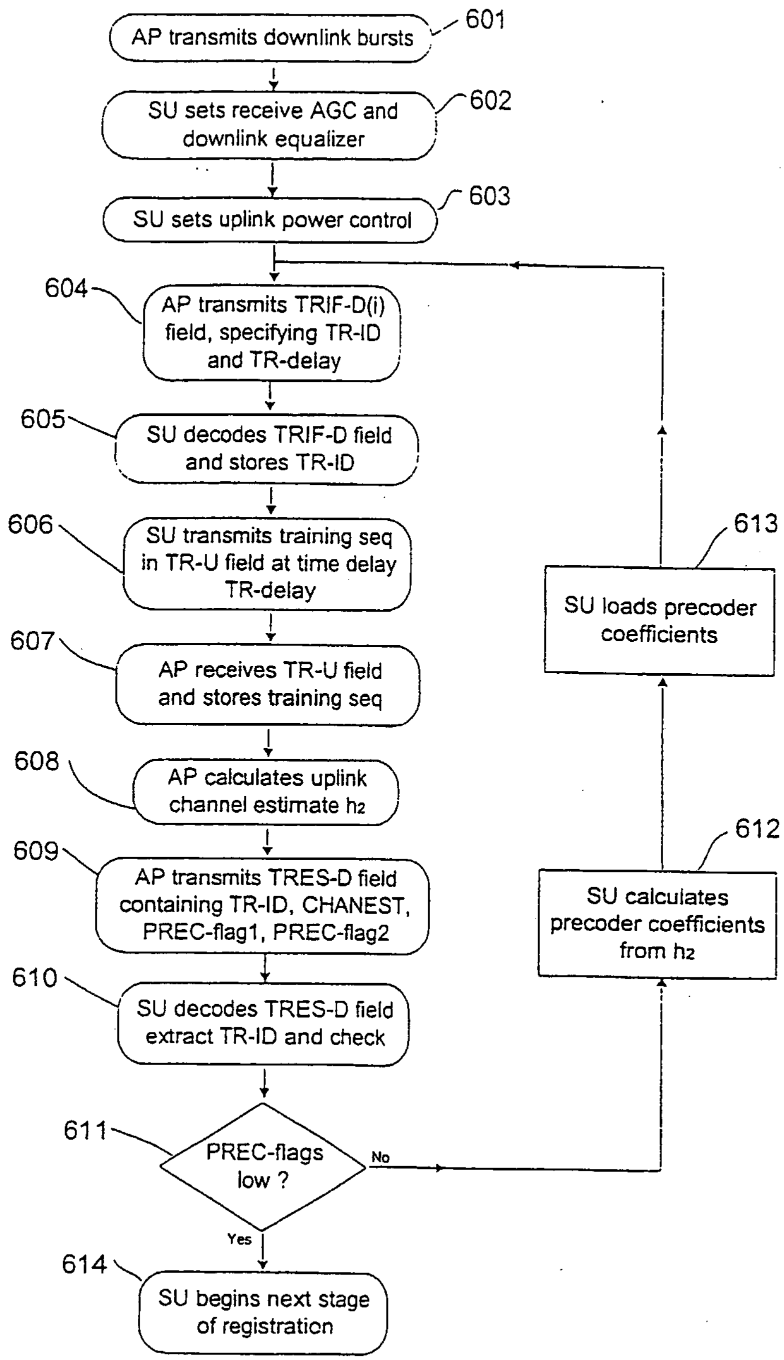

AP transmits downlink bursts
601
SU sets receive AGC and downlink equalizer
602
SU sets uplink power control
603
604
AP transmits TRIF-D(i) field, specifying TR-ID and TR-delay
605
SU decodes TRIF-D field and stores TR-ID
606
SU transmits training seq in TR-U field at time delay TR-delay
607
AP receives TR-U field and stores training seq
608
AP calculates uplink channel estimate h2
609
AP transmits TRES-D field containing TR-ID, CHANEST, PREC-flag1, PREC-flag2
610
SU decodes TRES-D field extract TR-ID and check
611
PREC-flags low ?
No
Yes
614
SU begins next stage of registration
613
SU loads precoder coefficients
612
SU calculates precoder coefficients from h2

Figure 6

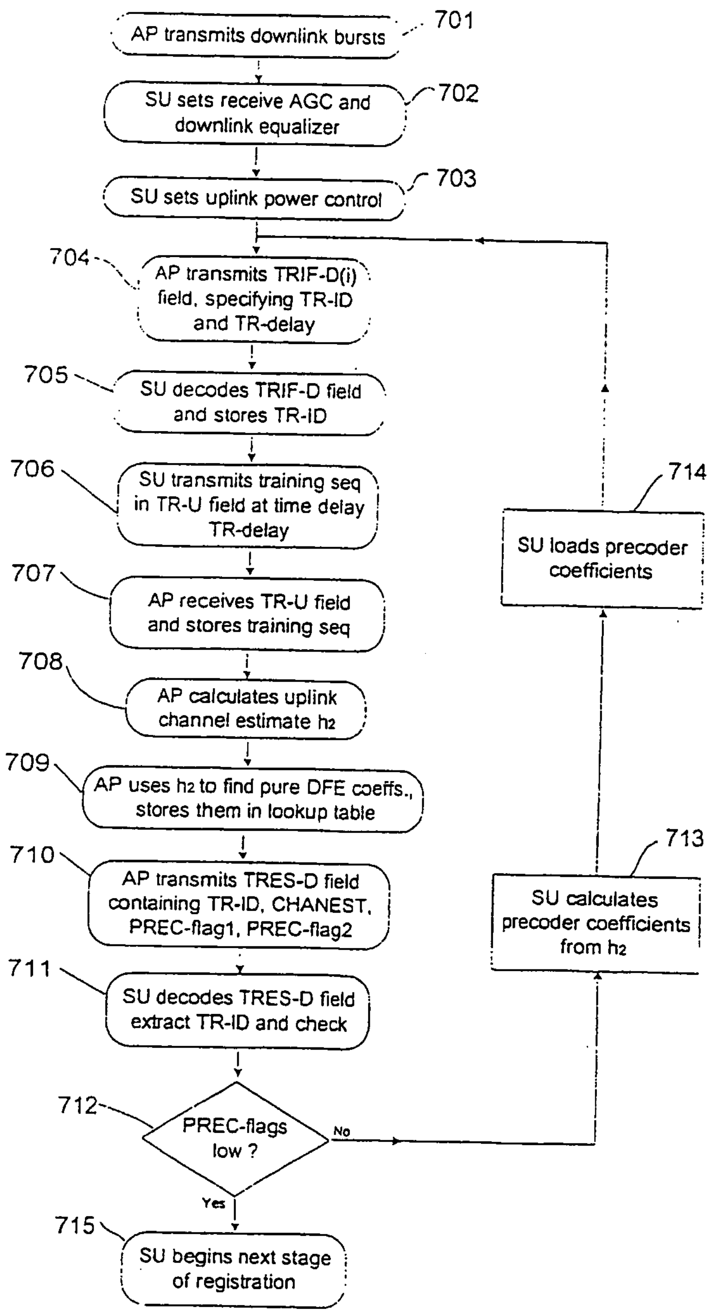

AP transmits downlink bursts
701
SU sets receive AGC and downlink equalizer
702
SU sets uplink power control
703
704
AP transmits TRIF-D(i) field, specifying TR-ID and TR-delay
705
SU decodes TRIF-D field and stores TR-ID
706
SU transmits training seq in TR-U field at time delay TR-delay
707
AP receives TR-U field and stores training seq
708
AP calculates uplink channel estimate h2
709
AP uses h2 to find pure DFE coeffs., stores them in lookup table
710
AP transmits TRES-D field containing TR-ID, CHANEST, PREC-flag1, PREC-flag2
711
SU decodes TRES-D field extract TR-ID and check
712
PREC-flags low ?
No
Yes
715
SU begins next stage of registration
714
SU loads precoder coefficients
713
SU calculates precoder coefficients from h2

Figure 7

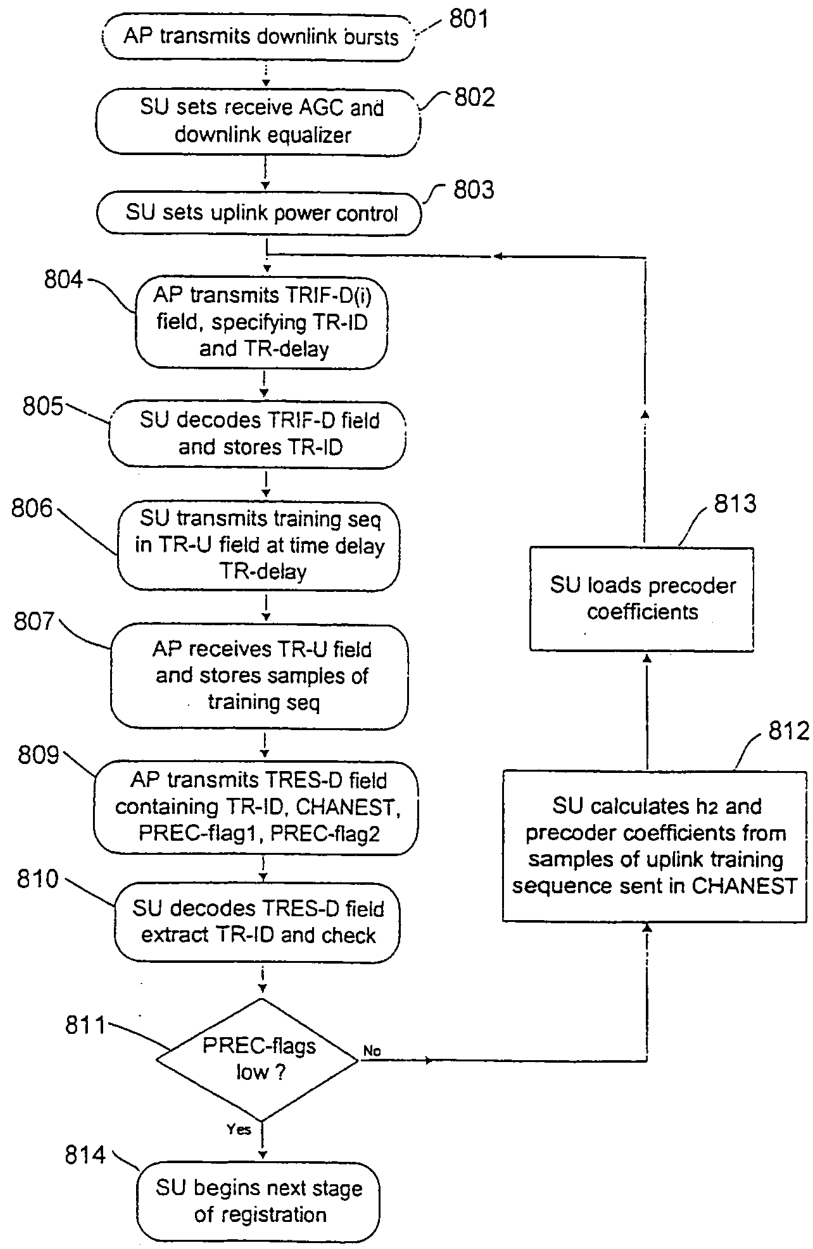

801
AP transmits downlink bursts
802
SU sets receive AGC and downlink equalizer
803
SU sets uplink power control
804
AP transmits TRIF-D(i) field, specifying TR-ID and TR-delay
805
SU decodes TRIF-D field and stores TR-ID
806
SU transmits training seq in TR-U field at time delay TR-delay
807
AP receives TR-U field and stores samples of training seq
809
AP transmits TRES-D field containing TR-ID, CHANEST, PREC-flag1, PREC-flag2
810
SU decodes TRES-D field extract TR-ID and check
811
PREC-flags low ?
No
Yes
814
SU begins next stage of registration
812
SU calculates h2 and precoder coefficients from samples of uplink training sequence sent in CHANEST
813
SU loads precoder coefficients

Figure 8

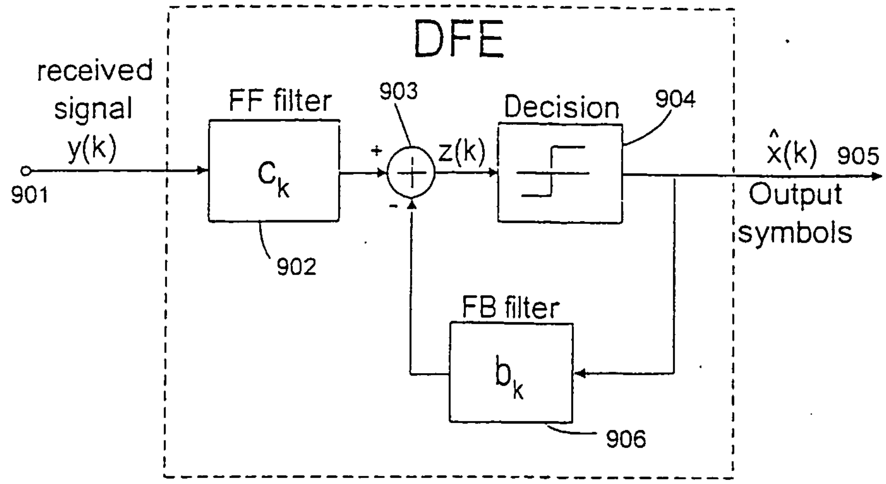


Figure 9

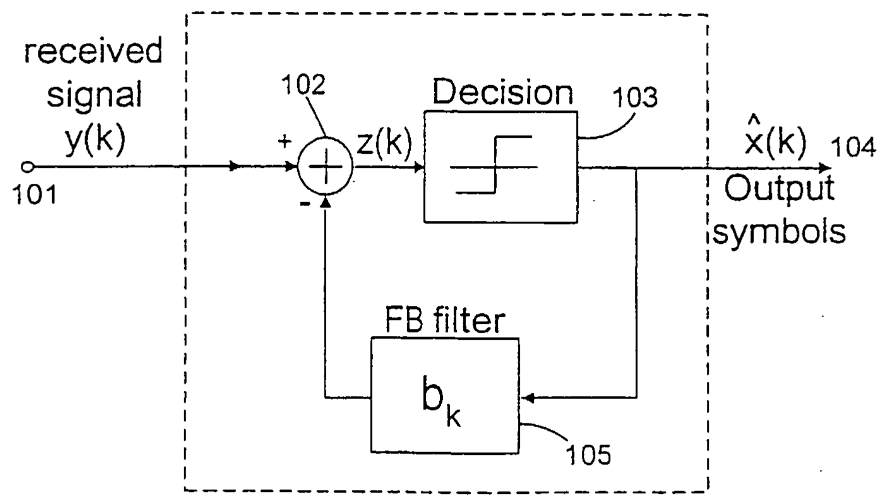


Figure 10

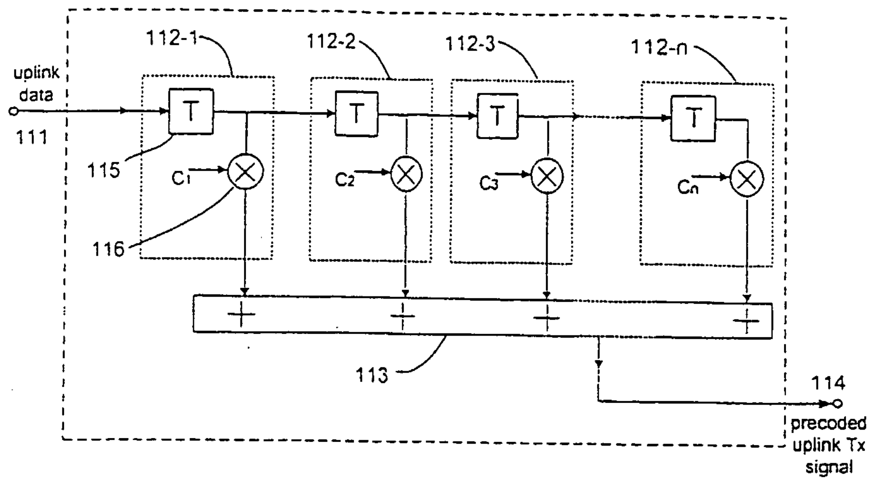

uplink data
111
112-1
112-2
112-3
112-n
T
T
T
T
115
116
C1
C2
C3
Cn
113
114
precoded uplink Tx signal

Figure 11

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WIRELESS TRANSMISSION SYSTEM AND METHOD

The invention relates to a method of setting the characteristics of a precoder in a subscriber unit in a point to multi-point wireless transmission system comprising an access point and a plurality of subscriber units. The invention further relates to a point to multi-point wireless transmission system comprising an access point and the plurality of subscriber units and to a subscriber and to an access point for use in such a wireless transmission system.

In fixed wireless access systems the signal processing burden at the access point can be excessive since the access point has to deal with many individual subscriber channels. In frequency division duplex systems this burden is increased with respect to time division duplex systems as each subscriber has two channels, an upstream channel and a downstream channel. By far the greatest complexity is required for equalisation at the access point because it must equalise signals from many different subscriber units in quick succession. The subscriber units are transmitting to the access point over channels having widely different impulse responses.

In a fixed wireless access system multipath interference is a major obstacle to high speed data transmission. Multipath interference arises when the radio signal is reflected and diffracted by objects in its path such as buildings, trees, and even vehicles. Multipath

interference causes echoes from a particular data symbol to overlap with neighbouring symbols and this is known as inter symbol interference. Some form of equalisation is necessary to remove the inter symbol interference from the received signal if data is to be transmitted at high symbol rates. The equalisation process requires complicated signal processing and for high speed real time data communication systems this is a significant burden.

In a point to multi-point system each subscriber unit only receives data from a single access point and downstream data bursts can often be heard by all subscriber units. As a result each subscriber unit has plenty of time to train its equaliser on the downstream data bursts. Upstream data transmission, however, occurs between many different subscriber units and a single access point. As a result the access point has a very heavy equalisation burden since the upstream channels from the different subscriber units will all have different characteristics particularly with respect to their impulse responses. This problem is increased during random access slots or contention slots where the identity of the subscriber unit which is transmitting, and hence the impulse response of the channel over which it is transmitting, is unknown to the access point. In addition, the contention burst is normally very short. As a result the access point must retrain its equaliser in the very short time between bursts from different subscribers. For downstream transmissions a particular SU will normally have a long time interval during which it may perform processing on the received signal before it is required to respond to the AP. On upstream transmissions, however, the AP receives many data bursts from different SUs in rapid

succession and it has to respond to each one immediately. As a result, it is possible to perform complex processing of downstream transmission signals at the SU whereas because of the time restraints it is not possible to perform the same complex processing at the AP for upstream transmissions unless the processing power at the AP vastly exceeds that at the SUs.

It is known that it is possible to shift the equalisation load from the receiver to the transmitter of a communications system by making use of pre-equalisation or precoding. US Patent No. 6031866 discloses a method which reduces computational load at the subscriber terminals by performing all equalisation and precoding at the access point. In this configuration registration of the new subscriber is easy because the access point has full equalisation capability. Consequently when a new subscriber wishes to register it simply transmits a registration request during a random access slot or registration slot. The access point receives the registration burst distorted by multipath interference and performs full equalisation before decoding the signal. On the downstream transmission the access point makes use of the time division duplex channel reciprocity to precode or pre-equalise the signal before transmission so that when the registration acknowledgment signal arrives at the subscriber unit it is free from multipath interference.

It is possible to transfer all equalisation and precoding from the access point to the subscriber unit in a time division duplex system. On the downstream link the subscriber units can calculate equalisation coefficients since each subscriber unit only receives transmissions

from a single access point on a single channel. In time division duplex systems the downstream equaliser coefficients calculated in the subscriber unit may then be used in a precoder in the subscriber unit to pre-equalise the signal before upstream transmission. This is possible because of time division duplex channel reciprocity, that is the upstream and downstream channels are identical. In a frequency division duplex system however there is no such simple method for the subscriber unit to calculate the precoder coefficients because the upstream and downstream channels are different and their characteristics are not correlated. This may also apply to time division duplex systems where the channel characteristics are changing quickly and may change between the time that the access point is transmitting and the time when the subscriber unit transmits to the access point.

The invention provides a method of setting the characteristics of a precoder in a subscriber unit (SU) in a point to multi-point wireless transmission system comprising an Access Point (AP) and a plurality of SUs, the method comprising the steps of:

a) causing the AP to transmit sequential downstream data frames, at least some of which contain a training identifier field, each training identifier field containing a unique identifier and defining a time at which an associated upstream training test field occurs;

b) causing the SU, as a result of receiving and decoding the training identifier field, to store the unique identifier and to generate and transmit an upstream test sequence in the training test field;

c) causing the AP to store samples of the received training test sequence;

d) causing the AP to transmit a training response field at a later time in the frame or in a subsequent frame, the training response field containing the unique identifier from the training identifier field and data representing the impulse response of the upstream channel; and

e) causing the SU to adjust its precoder characteristics when it detects a training response field containing the stored unique identifier in accordance with the upstream channel impulse response data.

The method according to the invention enables a subscriber unit to obtain information about the upstream channel between it and the access point from the access point without the access point having to establish which subscriber unit is transmitting to the access point or to decode the data sent by the subscriber unit. Thus the characteristics of the upstream channel can be relayed to the subscriber unit without the access point having to decode the data sent by the subscriber unit. This reduces the equalisation burden required at the access point since the upstream data transmission does not have to be equalised before the channel characteristics are relayed to the subscriber unit. As a result the subscriber unit can derive the upstream channel characteristics and pre-distort the data sent to the access point to reduce the equalisation burden at the access point. This advantage is particularly useful in a frequency division duplex system where the upstream and downstream channels are different and so measurement of downstream channel impulse response at the subscriber unit does not provide a

reliable estimate for the upstream channel impulse response.

Steps (b) to (e) may be repeated until the access point indicates that it can decode the data transmitted by the subscriber unit. The training response field may contain a flag indicating whether the access point can decode the data transmitted by the subscriber unit without any further adjustment of the precoder characteristics.

By providing a flag in the training response field the subscriber unit can be inhibited from attempting to obtain further data representing the upstream channel impulse response from the access point. Thus an individual subscriber unit that has received and decoded the flag will no longer attempt to use the training identifier field leaving the other subscriber units free to do so.

In step (b) the subscriber unit may wait for a random number of frames before storing the unique identifier and transmitting the upstream test sequence. This minimises the probability of two subscriber units trying to obtain upstream channel impulse response data in the same frame.

The method may comprise the further step of causing the AP to calculate the impulse response of the upstream channel from samples of the stored upstream training test sequence wherein the data transmitted in the training response field represents the calculated impulse response of the upstream channel. Alternatively, the access point may transmit the samples of the received training test sequence in the training response field as the data representing the impulse response of the upstream channel.

This alternative reduces the processing burden on the access point as the subscriber unit will then calculate the upstream channel impulse response from the samples of the received upstream training test sequence. The subscriber unit is able to do this because the downstream communications link from the AP to the SU has already been established.

The invention further provides a point to multi-point wireless transmission system comprising an Access Point (AP) and a plurality of subscriber (SUs), wherein:

the AP comprises means for transmitting sequential downstream data frames, at least some of which contain a training identifier field, each training identifier field containing a unique identifier and defining a time at which an associated upstream training test field occurs;

the SU comprises means for receiving the transmitted downstream data frames and decoding the training identifier field, means for storing the unique identifier and for generating and transmitting an upstream test sequence in the training test field;

the AP further comprises means for storing samples of the received test sequence and for transmitting a training response field at a later time in the frame or in a subsequent frame, the training response field containing the unique identifier from the training identifier field and data representing the upstream channel impulse response; and

the SU further comprises means for adjusting its precoder characteristics in accordance with the data representing the upstream channel impulse response when it detects a training response field containing the stored unique identifier.

The training response field may include a flag to indicate whether the access point is able to decode the upstream test sequence and the subscriber unit may further comprise means responsive to the detection of the flag to inhibit further transmission of the upstream test sequence.

The access point may comprise means for calculating the upstream channel impulse response from the samples of the training test sequence and transmitting data representing the calculated impulse response in the training response field. Alternatively the access point may transmit the samples of the upstream training test sequence as data representing the upstream channel impulse response and the subscriber unit may comprise means for calculating the upstream channel impulse response from the samples of the received upstream stored training test sequence.

The invention still further provides a subscriber unit for use in a point to multi-point wireless transmission system according to the invention, the subscriber unit comprising a precoder having adjustable characteristics, means for receiving from the access point downstream data frames and decoding the training identifier field, means for storing the unique identifier and for generating and transmitting an upstream test sequence in the training test field, and means for adjusting the characteristics of its precoder, when it detects a training response field in a downstream data frame transmitted by the access point containing the stored unique identifier, in accordance with the received data representing the upstream channel impulse response.

Such a subscriber unit is able to pre-distort the data transmitted to the access point to compensate for the

channel impulse response between the subscriber unit and access point. The subscriber unit is able to obtain data from the access point enabling the upstream channel impulse response to be established without the access point having to establish which subscriber unit is transmitting or decoding any data transmitted by the subscriber unit. This reduces the processing burden on the access point as either full or partial pre-distortion may be carried out by the subscriber unit even before the subscriber unit is identified by the access point.

The subscriber unit may comprise means for receiving the samples of the upstream training test sequence from the access point and calculating therefrom the adjustment needed to the precoder characteristics to compensate for the impulse response of the upstream channel. By transferring the calculation of the adjustment needed to the precoder characteristics from the access point to the subscriber unit a further simplification of the access point is possible.

The invention yet further provides an access point for use in a system according to the invention, the access point comprising means for transmitting sequential downstream data frames, at least some of which contain a training identifier field, each training identifier field containing a unique identifier and defining a time at which an associated upstream training test field occurs, means for receiving an upstream test sequence from a subscriber unit, means for storing samples of the received training test sequence and means for transmitting a training response field at a later time in the frame or in a subsequent frame, the training response field containing

the unique identifier from the training identifier field and data representing the impulse response of the upstream channel.

An access point as set forth in the preceding paragraph does not need to know the identity of the subscriber unit in order to transmit to the subscriber unit data representing the channel impulse response of the upstream channel from the subscriber unit to the access point. Thus the access point does not have to be able to decode the data from the subscriber unit but may merely derive from it the channel impulse response. The access point knows the training sequence as this is a pre-defined sequence which is sent by all subscriber units and it can derive the upstream channel impulse response from the difference between the received signal and the known training test sequence. The particular subscriber unit that transmitted the training test sequence will be addressed by the unique identifier which was sent in the training identifier field and stored by the subscriber unit. The AP transmits this same identifier number in the training response field so that the subscriber unit which sent the training test sequence will recognise that the training response field is addressed to it.

The training response field may include a flag, the AP comprising means for setting the flag when it can decode the received training test sequence. The training response field may contain a further flag, the access point comprising means for setting the further flag when it detects that there are no precursors in the training test sequence.

By using these flags the subscriber unit can determine whether or not it should seek to further adjust the precoder settings.

The above and other features and advantages of the invention will be apparent from the following description, by way of example, of embodiments of the invention with reference to the accompanying drawings, in which:

Figure 1 shows in block schematic form a prior art point to multi-point fixed wireless access system,

Figure 2 shows in block schematic form a first embodiment a point to multi-point fixed wireless access system according to the invention,

Figure 3 shows a second embodiment of a point to multi-point fixed wireless access system according to the invention,

Figure 4 shows upstream and downstream frames used in a method of setting the characteristics of a precoder in a subscriber unit according to the invention,

Figure 5 shows in expanded form some of the fields in the frames illustrated in Figure 4,

Figure 6 is a flow diagram illustrating a first embodiment of a method of setting the characteristics of a precoder in a subscriber unit according to the invention,

Figure 7 is a flow diagram illustrating a second embodiment of a method of setting the characteristics of a precoder in a subscriber unit according to the invention,

Figure 8 is a flow diagram illustrating a third embodiment of a method of setting the characteristics of a precoder in a subscriber unit according to the invention,

Figure 9 shows in block schematic form a decision feedback equaliser,

Figure 10 shows in block schematic form a non-linear decision feedback equaliser, and

Figure 11 shows in block schematic form a linear precoder for use in a subscriber unit according to the invention.

Figure 1 shows in block schematic form a known point to multi-point fixed wireless access system comprising an access point 1 and a plurality of subscriber units 2-1 to 2-n. The access point 1 has a data input 3 which feeds a precoder 4. The output of the precoder 4 is fed to an antenna 5 for transmitting the data from the access point to the subscriber units 2-1 to 2-n. The access point is also configured to receive data from the subscriber units 2-1 to 2-n and data received via the antenna 5 is fed to an equaliser 6 for removing inter symbol interference and the output of the equaliser is fed to a data output 7. Each subscriber unit 2-1 to 2-n both transmits data to the access point AP from data inputs 8-1 to 8-n and receives data from the access point 1 and reproduces that data at data output 9-1 to 9-n. The system operates in a time division duplex mode and consequently the upstream and downstream data channels are identical. The access point 1 will detect the channel characteristics from each subscriber unit 2-1 to 2-n to the access point using the equaliser 6 and will be able to use the equaliser taps to adjust the precoder 4 so that the data from the access point arrives at each subscriber unit without any inter symbol interference.

As has been stated above it is possible to remove the complexity from the access point 1 and place it at the subscriber units 2-1 to 2-n, that is the precoding and

equalisation could take place at each subscriber unit rather than the access point. The system as shown in Figure 1 however relies on time division duplex transmission so that the upstream and downstream channels are identical. With a frequency division duplex system upstream and downstream channels are not identical and there is little or no correlation between the impulse responses of the upstream and downstream channels.

Figure 2 shows in block schematic form a first embodiment of a point to multi-point wireless transmission system according to the invention. As shown in Figure 2 the system comprises an access point 21 which communicates with a plurality of subscriber units 22-1, 22-2, ..., 22-n. Transmission between the access point and the subscriber unit is by means of a frequency division duplex system. This means that the upstream channel h_2 from each subscriber unit to the access point is different from the downstream channel h_1 from the access point to the subscriber units. In such a system the data bursts transmitted by the access point 21 may be received by all of the subscriber units 22-1 to 22-n. As a result each of the subscriber units has plenty of time to train its equaliser so that it can receive and decode the data transmitted by the access point 21. The subscriber units also include a precoder 24-1 to 24-n to pre-equalise the upstream transmission so that the access point does not require complicated equalisation. Before registration takes place, that is before the subscriber unit has registered with the access point, the subscriber unit listens to downstream transmissions broadcast from the access point. The subscriber unit first adjusts its AGC circuitry in order to receive the access point signal at

the correct amplitude. It then detects known training sequences embedded at intervals in the downstream signal and uses these known sequences for timing synchronisation, downstream channel estimation, and to set up the coefficients of the equaliser 23-1 to 23-n at each subscriber unit. This equaliser may take the form of a decision feedback equaliser. Once the equaliser 23 at the subscriber unit 22 has been initialised, the downstream data from the access point 21 can be de-coded by the subscriber unit.

In systems where the upstream h_2 and downstream h_1 channels are not the same, such as a frequency division duplex system, the downstream power control and channel response information cannot be used for the upstream channel. Consequently it is not possible to use the equaliser coefficients derived from the downstream channel characteristics to the precoder 24 in order to pre-distort the upstream data burst. Also in a system according to the invention the access point does not have full equalisation capability and so cannot decode the data transmitted by the subscriber unit unless it is first pre-equalised before transmission by the subscriber unit. Thus the subscriber unit has to obtain by some means an indication of the upstream channel characteristics before the subscriber unit can be identified to the access point and an upstream data transmission channel established.

In order to establish the characteristics of the upstream channel the access point transmits downstream frames 40, as shown in Figures 4 and 5, which include a training identifier field TRIF-D(i) 41 which has a unique upstream training field TR-U(i) 51 associated with it, as shown in

Figures 4 and 5. The training identifier field TRIF-D(I) 41 contains a unique training identifier TR-ID 42 under timing offset TR-delay 43 which specifies the timing delay of the associated upstream field TR-U(i) 51 within the uplink frame 50. When a subscriber unit wishes to begin the precoder initialisation process it decodes the downstream frame 40 and extracts the next occurring training identifier field TRIF-D(j) 41 which specifies the training identifier TR-ID(j) 42 and the timing offset TR-delay(j) 43 for the corresponding upstream training field TR-U(j) 51. The subscriber unit stores the training identifier TR-ID 42 in memory and then transmits a known training sequence (which has good autocorrelation properties) during the upstream field TR-U(j) 51 at a time location specified by the timing offset TR-delay 43. The training sequence is not pre-equalised (or precoded) by the subscriber unit because the precoder coefficients have not yet been determined. The access point listens for any received signals during the upstream field TR-U(j) 51 and stores the received signal samples in memory. That is the access point samples the received training sequences (which is in a distorted analogue form) and digitises these samples so that they can be stored in a quantised digital form.

Since the access point does not have full equalisation capability it is not able to equalise and decode the received training sequence. The access point performs simple channel estimation based on the received signal samples to calculate the uplink channel impulse response h_2, the access point then transmits the estimated channel response h_2 back to the subscriber unit. For each training identifier field TRIF-D(j) 41 there is also a

downstream field known as the training response field TRES-D(j) 45 which may occur either later in the same downstream frame or in a subsequent downstream frame. After estimating the upstream channel response h_2 the access point then transmits a training response field TRES-D(j) 45 which contains the training identifier TR-ID(j) 42 followed by a field CHANEST 46 which consists of the uplink channel impulse response h_2,and then followed by two flags PREC-flag 1(j) 47 and PREC-flag 2(j) 48. The flag PREC-flag 1 47 is set to be high if there are any precursors found in the upstream channel response h_2 and is set to be low otherwise. The flag PREC-flag 2(j) 48 is set to be low only if the received training signal has sufficiently low distortion for the access point to be able to equalise it without any further precoding otherwise it is set to be high.

The access point does not have any knowledge of which subscriber unit was transmitting during the upstream training field TR-U(j) 51 since the subscriber unit has not transmitted its identity and the access point could not decode any transmitted identity as it does not have full equalisation capability. The subscriber unit listens to all subsequent training response fields TRES-D 45 occurring after the upstream training field TR-U(j) 51 was transmitted and for each training response field TRES-D 45 checks to see whether the training identity TR-ID matches the stored training identity TR-ID(j) 42. If a match is found then the subscriber unit equalises the rest of the received pracket TRES-D 45 and extracts CHANEST 46 and PREC-flag 1 47 and PREC-flag 2 48. The subscriber unit then uses the estimated upstream channel impulse response h_2 (contained in CHANEST 46) to calculate

precoder coefficients for the upstream transmission. The flag PREC-flag 1 47 is used by the subscriber unit because it indicates whether or not precursor echoes were found in the received uplink signal. The flag PREC-flag 2 48 indicates whether or not there was significant multipath distortion. If flag PREC-flag 2 is high then the subscriber unit should perform as much precoding as possible. If the flag PREC-flag 2 is low and no precursors were found, that is PREC-flag 1 is low, then the current precoding at the subscriber unit is sufficient for the access point to decode the uplink signal.

After the subscriber unit has calculated the precoder coefficients it initialises the precoder with those coefficients and waits for a later training identifier field TRIF-D 41 and then transmits a second training sequence in the corresponding training field TR-U 51. This process continues until both flags PREC-flag 1 47 and PREC-flag 2 48 are low indicating to the subscriber unit that there were no precursors in the received uplink training signal TR-U 51 and that the access point is able to decode the training sequence TR-U 51. In this case the access point attaches a unique temporary subscriber identity SU-ID temp to the end of the training response field TRES-D 45 that the subscriber unit must use for registration. Equalisation and precoding is now initialised at both ends of the communication link and the subscriber unit can then transmit a registration request to the access point using the temporary SU-ID temp identifier. All transmissions from the subscriber unit are now pre-coded and so can be decoded correctly at the access point.

In the embodiment of the invention shown in Figure 2 the access point has no equalisation capability for the signal that is received on the upstream channels from the subscriber units. Thus each subscriber unit has to fully precode the upstream data transmitted to the access point. In a second embodiment of the invention shown in Figure 3 the system comprises an access point 31 which communicates with a plurality of subscriber units 32-1, 32-2, 32-n. Each subscriber unit comprises an equaliser 38 on the receive side which may take the form of a decision feedback equaliser as shown in Figure 9, and a precoder 34 which pre-distorts the data sent to the access point 31 over the upstream data channel. The access point includes a pure decision feedback equaliser 35 which may take the form of that shown in Figure 10. In this embodiment the access point performs partial equalisation of the upstream signal. The reason for this is that full precoding at the subscriber unit is not always feasible because the upstream channel impulse response h_2 may occasionally contain critical zeros located very close to the unit circle. These critical zeros result in a very long precoder which may not be feasible to implement in practice. Another problem arises when a non-linear precoder such as Tomlinson- Harashima precoder, is used at the transmitter. In this case the precoder stability is a problem and results in degraded error rate performance. As a consequence the embodiment shown in Figure 3 uses only a linear precoder 34 at the subscriber unit, that is a precoder composed of a linear finite impulse response filter, such as that shown in Figure 11. To complete the equalisation process a pure non-linear decision feedback equaliser composed of an infinite impulse response filter is used at the access point. A pure non-linear decision

feedback equaliser is a type of decision feedback equaliser that has only a feedback filter and no feed forward filter such as that shown in Figure 10. The pure non-linear decision feedback equaliser 35 is not able to fully equalise the upstream channel h_2 unaided but is used in conjunction with the linear precoder 34 at the subscriber unit. Thus the equalisation process of the upstream channel is shared jointly between the access point and the subscriber unit. The complexity required of the AP is very low as the pure non-linear decision feedback equaliser may be constructed from simple adder trees, because the feedback symbols are discrete information points rather than full precision samples which would require full multipliers as in a linear equaliser. Furthermore, the precoder at the subscriber unit is only a linear precoder without any feedback path which avoids the stability problems associated with feedback precoders.

In the embodiment shown in Figure 3 where partial equalisation of the upstream channel takes place at the access point it is necessary for the access point to calculate coefficients for the pure non-linear decision feedback equaliser 35 based on the received training signal TR-U 51 transmitted by the subscriber unit. A pure non-linear decision feedback equaliser allows a very low complexity solution because the decision feedback equaliser coefficients correspond to the estimate of the upstream channel impulse response h_2. Thus the channel estimation process performed by the access point also produces the non-linear decision feedback equaliser coefficients without any extra calculation. The operation for initialising the decision feedback equaliser

coefficient will be described with reference to Figure 7 hereinafter. Once the decision feedback equaliser coefficients have been calculated they are stored in a look-up table at the access point in a location referenced by SU-ID temp. When registration is complete the SU-ID temp is replaced by the true SU-ID, that is by the identity of the subscriber unit. When subsequent upstream data transmissions are received from a registered subscriber unit the decision feedback equaliser coefficients referenced by the SU-ID are retrieved from the look-up table in the access point and loaded into the non-linear decision feedback equaliser at the access point. This makes the system very efficient because the decision feedback equaliser coefficients are only calculated once at the access point and then are simply referenced from the look-up table subsequently.

In a further embodiment the access point is designed for lowest complexity. To reduce the processing power available at the access point even further the processing power is not used for channel estimation. Instead of transmitting the channel estimate h_2 back to the subscriber unit the access point simply re-transmits the vector of distorted signal samples received from the subscriber unit Yvec to the subscriber unit over the downstream channel during the CHANEST 46 part of the training response field TRES-D 45. The subscriber unit decodes the distorted received signal samples Yvec and performs channel estimation to calculate the upstream channel response h_2 and then calculates the precoder coefficient values as before. In this embodiment complexity at the access point is greatly reduced. There is, however, increased transmission overhead on the downstream channel for re-

transmitting the samples of Yvec back to the subscriber unit and extra processing is required at the subscriber unit for channel estimation. If full precoding does not take place at the subscriber unit then as well as calculating the precoder coefficient values the subscriber unit may also transmit to the access point the coefficients for the pure decision feedback equaliser located in the access point. Alternatively, the AP may have sufficient time to calculate the decision feedback equaliser co-efficients before the upstream transmission from the SU takes place, even though it had insufficient processing power to calculate the upstream channel impulse response before transmitting the training response field TRES-D 45 to the SU.

Figure 6 is a flow diagram illustrating a method of setting the characteristics of a precoder in a subscriber unit in the embodiment of Figure 1 of a point to multi-point wireless transmission system. The method starts with step 601 in which the access point transmits downstream data bursts which may be received by any subscriber unit within the range of the access point. The next step of the method, step 602, consists of the subscriber unit setting its receive automatic gain control and downstream equaliser to enable it to decode the data transmitted by the access point. The next step 603 is for the subscriber unit to set its upstream power control, that is to set its transmit power so that the received signal at the access point is at the desired level. This may be achieved in the manner described in our co-pending application (42557). The next step 604 consists of the access point transmitting a training identifier field TRIF-D(i) 41 specifying a training identity TR-ID 42 and a

timing offset TR-delay 43. The training identity TR-ID 42 is a unique number which changes every frame and the timing offset TR-delay 43 represents a time at which the access point will expect to receive a training sequence from any subscriber unit that is requesting initialisation. The next step 605 is for the subscriber unit to decode the training identifier TRIF-D 41 and to store the training identifier TR-ID 42 contained within the training identifier field. The next step 606 then consists of the subscriber unit transmitting a pre-determined training sequence in the upstream training field TR-U 51 at a timing offset TR-delay 43 defined by the training identifier field TRIF-D 41. Step 607 consists of the access point receiving the upstream training field TR-U 51 and storing the samples of the training sequence. Step 608 consists of the access point calculating the uplink channel estimate h_2 from the stored samples of the training sequence. It will be apparent to the person skilled in the art that the training sequence is a known sequence and the access point may calculate the effect of the upstream channel on the transmitted signal from the subscriber unit by comparing the received training sequence with the pre-determined sequence. See, for example, US Patent No. 5559723 (Mourot et.al.) In step 609 the access point transmits a training response field which contains the training identity TR-ID 42, the channel estimate CHANEST 46, and two flags PREC-flag 1 47 and PREC-flag 2 48. In step 610 the subscriber unit receives and decodes the training response field TRES-D 45 and extracts the training identifier TI-ID 42. Then the SU compares the training identifier TR-ID 42 with that stored in step 605 and if the TR-IDs coincide then it determines that the rest of the training response field is

for itself and not one of the other subscriber units. The next step 611 is for the subscriber unit to determine whether the flags PREC-flag 1 47 and PREC-flag 2 48 are low. If they are not then the next step 612 is for the subscriber unit to calculate the precoder coefficients from the upstream channel estimate h_2 transmitted in the training response field. The next step 613 is for the subscriber unit to load the precoder coefficients calculated in step 612 into the precoder. The method then returns to the beginning of step 604 and this procedure is repeated until at step 611 the subscriber unit determines that the flags PREC-flag 1 47 and PREC-flag 2 48 are low. When this occurs the next step 614 is for the subscriber unit to begin the next stage of registration. A further step may be inserted between steps 613 and 604 where the subscriber unit waits for a random number of training identifier fields to be transmitted before it seeks to decode a further training identifier field and proceed with the training sequence. This minimises the possibility of two subscriber units continually trying to determine their precoder coefficients using the same training identifier field. It will be apparent that if two subscriber units transmit a training sequence in the same upstream training field then the channel estimate at the access point will be significantly different from the actual channel response of both subscriber units. By waiting a random number of training identifier fields before seeking to re-transmit a training sequence the possibility of both subscriber units re-transmitting at the same time is reduced.

Figure 7 is a flow diagram illustrating a method of setting subscriber unit precoder coefficients in a system

as shown in Figure 3. The first step in the method consists of the access point transmitting downstream data bursts which are receivable by all the subscriber units within the service area of the access point. The next step 702 consists of the subscriber unit setting its received AGC level and training its downstream equaliser so that it can decode data transmitted by the access point. The next step 703 is for the subscriber unit to set its upstream power control, that is the transmit power for data sent to the access point. Step 704 represents the access point transmitting a training identifier field TRIF-D 41 which contains the training identifier TR-ID 42 and the timing offset TR-delay 43. In step 705 the subscriber unit decodes the training identifier field TRIF-D 41 and stores the training identifier TR-ID 42. In step 706 the subscriber unit then transmits the training sequence in the upstream training field TR-U 51 at a time offset from receiving the training identifier field TR-delay 43. In step 707 the access point receives the upstream training field TR-U 51 and stores the sampled training sequence. This is followed by step 708 in which the access point calculates the upstream channel estimate h_2. In step 709 the access point uses the upstream channel estimate h_2 to determine the coefficients for the pure decision feedback equaliser and stores them in a look-up table in a location referenced by SU-ID temp. In step 710 the access point then transmits a training response field TRES-D 45 containing the training identifier TR-ID 42, the upstream channel estimate CHANEST 46, and two flags PREC flag 1 47 and PREC flag 2 48. In step 711 the subscriber unit receives and decodes the training response field TRES-D 45 and if it determines from the training identifier TR-ID 42 that the

transmission is for it, that is the number matches that stored in step 705, then it determines in step 712 whether the flags PREC flag 1 47 and PREC flag 2 48 are low. If not, it calculates in step 713 the precoder coefficients from the upstream channel response sent in the portion CHANEST 46 of the training response field TRES-D 45. It then steps to step 714 where the subscriber unit loads the precoder coefficients into the precoder 34 in preparation for transmitting a further training sequence to the access point. From step 714 it re-enters the process at step 704. If at step 712 the subscriber unit determines that the flags are low, then it proceeds to step 715 which represents the subscriber unit beginning the next stage of registration. When registration has been achieved the access point will replace the location SU-ID temp with the identity of that subscriber unit SU-ID.

Figure 8 is a flow diagram of the procedure for initialising the precoder coefficients in a system where the access point is designed for lowest complexity and where there is not sufficient processing power available at the access point for channel estimation in real time, that is in time for transmission in the training response field TRES-D 45. The method is basically the same as that described with reference to Figure 6 until the end of step 807. In this case the access point does not calculate the upstream channel estimate h_2 but instead transmits the stored samples of the received upstream training sequence in the portion CHANEST 46 of the training response field TRES-D 45 in step 809. In step 812 the subscriber unit calculates the precoder coefficients from a knowledge of the received training sequence in portion CHANEST 46 of the training response field TRES-D 45 and of the actual

training sequence transmitted. Since the downstream communications link is already established the samples of the upstream training sequence stored in the AP can be transmitted back to the SU in the form of data. It will be apparent that the analogue signal received by the AP is digitised and stored to enable it to be transmitted back to the SU or to enable calculations to be performed in order to determine the decision feedback equaliser coefficients. From the data contained in CHANEST 46 the subscriber unit can then calculate the precoder coefficients and proceed to step 813 where it loads the precoder coefficients into the precoder 34. In all other respects the procedure illustrated in Figure 8 follows that described with reference to Figure 6, the steps having the same final two numbers being equivalent steps in the method.

Figure 9 shows in block schematic form a decision feedback equaliser which is suitable for use as the decision feedback equaliser 23 or 33 in the subscriber unit 22 or 32 as shown in the system Figure 2 or of Figure 3. The decision feedback equaliser has an input 901 which is connected to the input of a feed forward filter 902 whose output is fed to a first input of a subtractor 903. The output of the subtractor 903 is fed to the input of a decision circuit 904 whose output is connected to an output 905 of the decision feedback equaliser. The output of the decision circuit 904 is also fed to the input of a feedback filter 906 whose output is connected to the second input of the subtractor 903. The received signal from the access point is applied to the input 901 and the data symbols are derived from the output of the decision circuit 904. This is a conventional decision feedback

equaliser and will in known manner remove inter symbol interference from the signal transmitted by the access point and received at the subscriber unit. The coefficients for the filters will be derived within the subscriber unit from known training sequences which are transmitted by the access point 21 or 31. This is achieved in known fashion and there is ample time to perform this function as the access point will be continuously transmitting and all the subscriber units in the service area can detect the training sequences even before registering with the access point.

Figure 10 shows in block schematic form a pure non-linear decision feedback equaliser. It comprises an input 101 to which the signal received from the subscriber unit is applied. The input 101 is connected to a first input of a subtractor 102. The output of the subtractor 102 is fed to a decision circuit 103 whose output is connected to an output 104 of the decision feedback equaliser. The output of the decision circuit 103 is also connected to a feedback filter 105 whose output is fed to a second input of the subtractor 102. This decision feedback equaliser is suitable for use as the decision feedback equaliser 35 in the access point 31 shown in Figure 3. As has been described the coefficients for the feedback filter 105 are determined by the method illustrated in Figure 7.

Figure 11 shows in block schematic form a linear precoder suitable for use as the precoder 34 in the subscriber unit 32 of Figure 3. The linear precoder shown in Figure 11 has an input 111 to which data to be transmitted to the access point over the upstream channel is applied. The

input data is applied to the first stage of a plurality of delay stages 112-1 to 112-n. The output of the delay stages are fed to respective inputs of a summing arrangement 113 whose output is fed to an output 114 of the linear precoder from which the data to be transmitted to the access point is derived. The delay stages 112 comprise a delay element 115 whose output is connected to a first input of a multiplier 116. The output of the multiplier is connected to the respective input of the summing arrangement 113. A second input of the multiplier receives the precoder coefficients $C_1 \ldots C_n$ which have been calculated by the subscriber unit. It will be apparent that the linear precoder 34 in the subscriber units 32 and the pure non linear decision feedback equaliser 35 in the access point 31 together form a full decision feedback equaliser substantially of the form of that shown in Figure 9. By dividing the equalisation process of the signal transmitted by the subscriber unit to the access point between the subscriber unit and the access point, the necessity for full pre-distortion of the transmitted signal is eliminated and a linear precoder can be used, minimising the stability problems while the complexity of the access point can be kept relatively low. It is only necessary to determine the coefficients of the filter in the equaliser 35 at the initial set up stage. They are then stored in a look-up table in the access point at a location defined by the identity of the subscriber unit which is transmitting to the access point. In this way the complexity of the access point can be reduced while not requiring full pre-distortion of the signal transmitted by the subscriber units.

CLAIMS

1) A method of setting the characteristics of a precoder in a Subscriber Unit (SU) in a point to multi-point wireless transmission system comprising an Access Point (AP) and a plurality of SUs, the method comprising the steps of:

a) causing the AP to transmit sequential downstream data frames, at least some of which contain a training identifier field, each training identifier field containing a unique identifier and defining a time at which an associated upstream training test field occurs;

b) causing the SU, as a result of receiving and decoding the training identifier field, to store the unique identifier and to generate and transmit an upstream test sequence in the training test field;

c) causing the AP to store samples of the received training test sequence;

d) causing the AP to transmit a training response field at a later time in the frame or in a subsequent frame, the training response field containing the unique identifier from the training identifier field and data representing the impulse response of the upstream channel; and

e) causing the SU to adjust its precoder characteristics when it detects a training response field containing the stored unique identifier in accordance with the upstream channel impulse response data.

2) A method as claimed in Claim 1 in which steps b) to e) are repeated until the AP indicates that it can decode the data transmitted by the SU.

3) A method as claimed in Claim 1 or Claim 2 in which the training response field contains a flag indicating whether the AP can decode the data transmitted by the SU without any further adjustment of the precoder characteristics.

4) A method as claimed in any preceding claim in which in step b) the SU waits for a random number of frames before storing the unique identifier and transmitting the upstream test sequence.

5) A method as claimed in any preceding claim in which communication between the AP and the SUs is by frequency division duplex time division multiple access.

6) A method as claimed in any preceding claim comprising the further step of;

f) causing the AP to calculate the impulse response of the upstream channel from samples of the upstream training test sequence;

wherein the data transmitted in the training response field represents the calculated impulse response of the upstream channel.

7) A method as claimed in any of Claims 1 to 5 in which the samples of the upstream received training test sequence are transmitted by the AP in the training response field as the data representing the impulse response of the upstream channel.

8) A method of setting the characteristics of a precoder in a Subscriber Unit (SU) in a point to multi-point wireless transmission system comprising an Access

Point (AP) and a plurality of SUs, the method being substantially as described herein with reference to the accompanying drawings.

9) A point to multi-point wireless transmission system comprising an Access Point (AP) and a plurality of subscriber units SUs, wherein:

the AP comprises means for transmitting sequential downstream data frames, at least some of which contain a training identifier field, each training identifier field containing a unique identifier and defining a time at which an associated upstream training test field occurs;

the SU comprises means for receiving the transmitted downstream data frames and decoding the training identifier field, means for storing the unique identifier and for generating and transmitting an upstream test sequence in the training test field;

the AP further comprises means for storing samples of the received test sequence and for transmitting a training response field at a later time in the frame or in a subsequent frame, the training response field containing the unique identifier from the training identifier field and data representing the upstream channel impulse response; and

the SU further comprises means for adjusting its precoder characteristics in accordance with the data representing the upstream channel impulse response when it detects a training response field containing the stored unique identifier.

10) A system as claimed in Claim 9 in which the training response field includes a flag to indicate whether the AP is able to decode the upstream test

sequence and the SU further comprises means responsive to the detection of said flag to inhibit further transmission of the upstream test sequence.

11) A system as claimed in Claim 9 or Claim 10 in which the SU comprises means for waiting for a random number of frames before storing the unique identifier and transmitting the upstream test sequence.

12) A system as claimed in any of Claims 9 to 11 in which communication between the AP and SUs is by a frequency division duplex time division multiple access protocol.

13) A system as claimed in any of Claims 9 to 12 in which the AP includes means for calculating the upstream channel impulse response from the samples of the upstream training test sequence and for transmitting data representing the calculated impulse response in the training response field.

14) A system as claimed in any of Claims 9 to 12 in which the AP comprises means for transmitting the samples of the upstream training test sequence as data representing the upstream channel impulse response and the SU comprises means for calculating the upstream channel impulse response from the received samples of the upstream training test sequence.

15) A point to multi-point wireless transmission system comprising an Access Point (AP) and a plurality of SUs substantially as described herein with reference to the accompanying drawings.

16) A Subscriber Unit (SU) for use in a point to multi-point wireless transmission system as claimed in any of Claims 9 to 15, the SU comprising a precoder having adjustable characteristics, means for receiving from the AP downstream data frames and decoding the training identifier field, means for storing the unique identifier and for generating and transmitting an upstream test sequence in the training test field, and means for adjusting the characteristics of its precoder, when it detects a training response field in a downstream data frame transmitted by the AP, containing the stored unique identifier, in accordance with the received data representing the upstream channel impulse response.

17) A SU as claimed in Claim 16 comprising means for receiving the samples of the upstream training test sequence from the AP and calculating therefrom the adjustment needed to the precoder characteristics to compensate for the impulse response of the upstream channel.

18) An SU as claimed in Claim 16 or Claim17 comprising means responsive to detection of a flag in the received training response field to inhibit further transmission of the upstream test sequence.

19) An SU as claimed in any of Claims 16 to 18 comprising means for delaying the transmission of the upstream test sequence for a random number of frames.

20) A Subscriber Unit (SU) for use in a point to multi-point wireless transmission system as claimed in any of Claims 9 to 15, the SU being substantially as

described herein with reference to the accompanying drawings.

21) An Access Point (AP) for use in a system as claimed in any of Claims 9 to 15, the AP comprising means for transmitting sequential downstream data frames, at least some of which contain a training identifier field, each training identifier field containing a unique identifier and defining a time at which an associated upstream training test field occurs, means for receiving an upstream test sequence from Subscriber Units (SUs), means for storing samples of the received training test sequence, and means for transmitting a training response field at a later time in the frame or in a subsequent frame, the training response field containing the unique identifier from the training identifier field and data representing the impulse response of the upstream channel.

22) An AP as claimed in Claim 21 in which the training response field includes a flag and the AP comprises means for setting the flag when it can decode the received training test sequence.

23) An AP as claimed in Claim 22 in which the training response field contains a further flag and the AP comprises means for setting the further flag when it detects that there are no precursors in the training test sequence.

24) An AP as claimed in any of Claims 21 to 23 comprising means for calculating the impulse response of the upstream channel from the samples of the upstream training test sequence and transmitting data representing

the calculated upstream channel impulse response in the training response field.

25) An AP as claimed in any of Claims 21 to 23 comprising means for transmitting the samples of the upstream training test sequence as the data representing the impulse response of the upstream channel.

26) An Access Point (AP) for use in a point to multi-point wireless transmission system as claimed in any of Claims 9 to 15, the AP being substantially as described herein with reference to the accompanying drawings.

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Claims searched: 1-26

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): H4P (PRE)

Int Cl (Ed.7): H04L: 25/02 25/03

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	WO 99/16220 A1	[VATALARO]	
A	WO 98/37671 A1	[GLOBESPAN]	
A	DE 19810285 A1	[SIEMENS]	
X	US 5887027 A	[COHEN] See abstract.	1,9,16,21 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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